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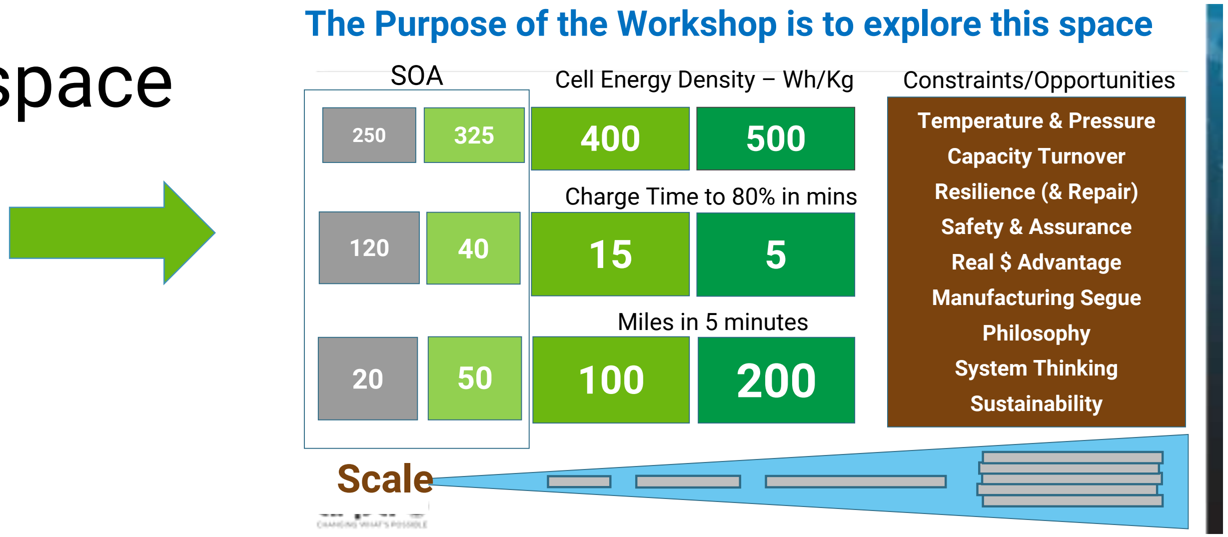
The Journey to Net Zero in Transportation

Part 1. Fast Charging High Energy Batteries for Passenger Vehicles & light Trucks & Vans

Dr. Halle Cheeseman – October 26th, 2021

Executive Summary – High Energy, Fast Charging Batteries

- The Market for EVs is set to grow substantially the next 20 years
- Net Zero Emissions in Transportation will need our help
- EV Range and Charge Time detract from maximizing demand
  - 400 miles @ ICE cost & charging to 80% in 15 minutes is the goal
- Lithium Metal batteries promise a *"Beyond Lithium-Ion"* Future.
- This Workshop will explore this space



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A Brief History of Electric Vehicles……….and enabling batteries

Global EV Sales to exceed 60 million cars and 70% of Market by 2040

Figure 4: Global passenger vehicle sales outlook by drivetrain – Economic Transition Scenario

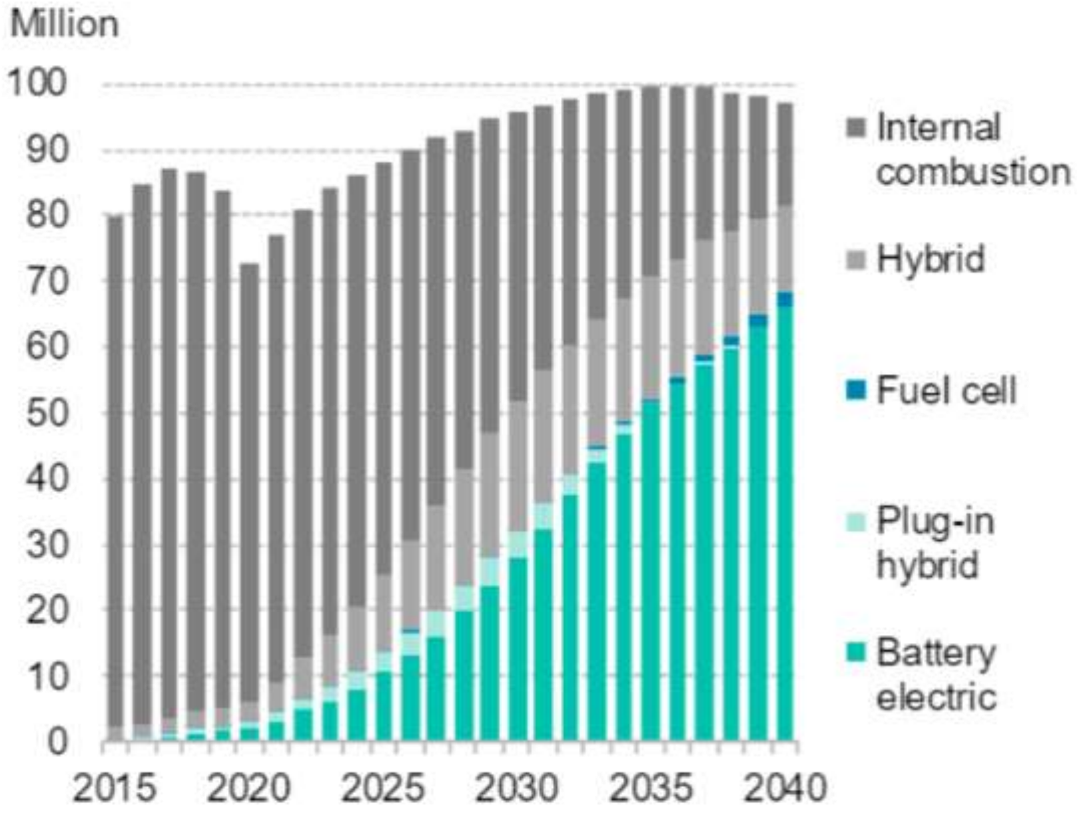
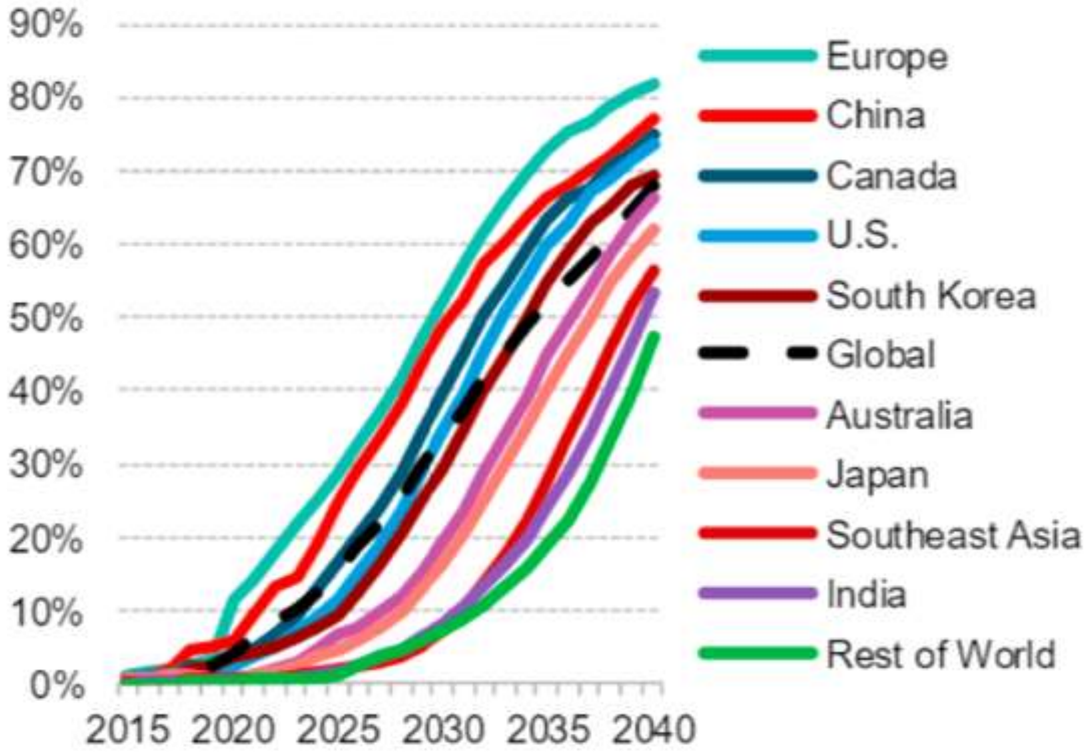
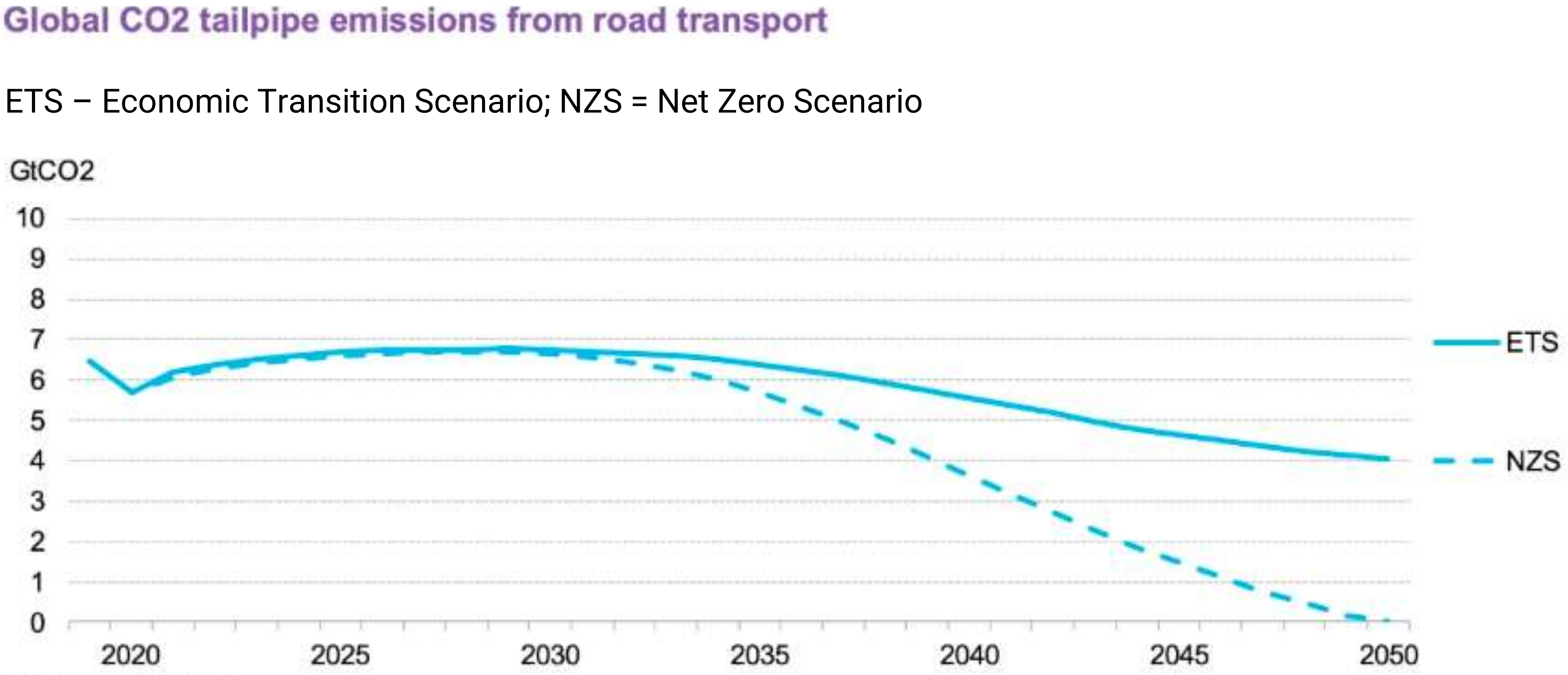


Figure 5: EV share of new passenger vehicle sales outlook by market – Economic Transition Scenario



Source: BNEF. Note: EVs include battery-electric and plug-in hybrid electric vehicles. Battery-electric vehicles represent 88% of total electric vehicle sales in 2030. Europe includes the EU, the U.K. and EFTA countries.

The base case doesn't get us to net zero – we need to do more



ETS – Economic Transition Scenario; NZS = Net Zero Scenario

Source: BloombergNEF

Where in the World…will we end up?

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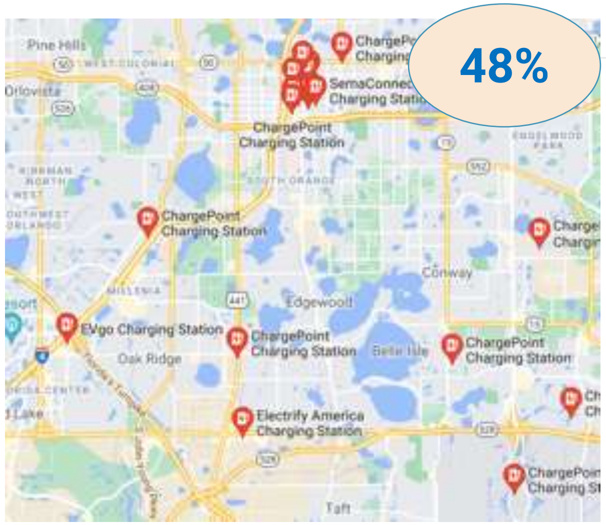
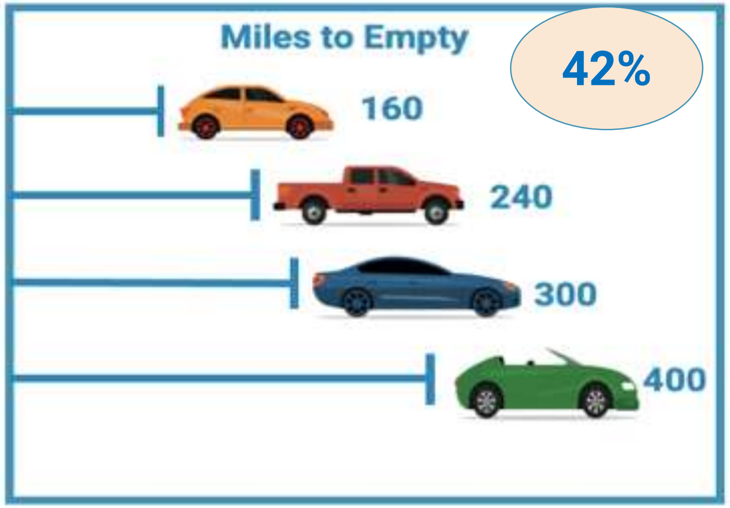
The decision to consider EV purchase has a number of detracting factors



Charger Public Access

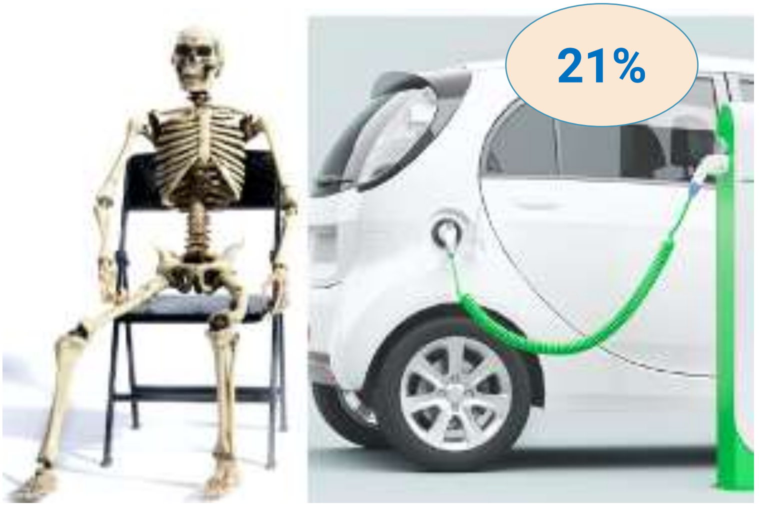
Price



Range

Ignorance

Home Access



Charge Time

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Ref Consumer Reports Survey – December 2020 – 3252 respondents

25% of people want over **400-mile Range**

How far would a plug-in electric vehicle have to be able to travel between charges for you to consider purchasing or leasing one?

	Total
	%
Less than 50 miles	2
50 miles to less than 100 miles	6
100 to less than 150 miles	9
150 to less than 200 miles	9
200 to less than 250 miles	11
250 to less than 300 miles	14
300 to less than 350 miles	14
350 to less than 400 miles	10
400 miles or more	25
Base: Respondents with a valid driver's license	3,359

Ref Consumer Reports Survey – December 2020

Note: Per FuelEconomy.gov – Median ICE Range (2016) – 412 miles

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Range is not an Energy issue so much as a cost issue

Table 4: BEV price parity with internal combustion vehicles by segment and country

Market					
BEV price parity period	2022-2025	2022-2027	2023-2028	2025-2030+	2023-2026

Source: BNEF, EPA, ICCT, FEV, ONRL, IDL. Note: Parity figures exclude home chargers.

*

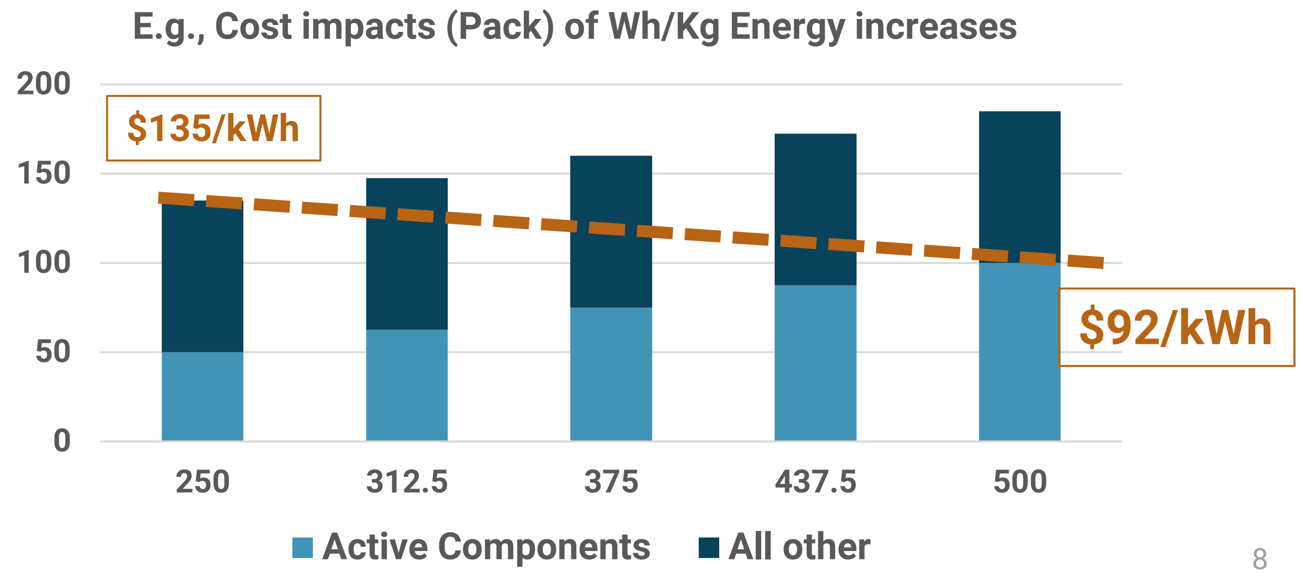
Credit BNEF

*** Note this is for an average vehicle range of approx. 250 miles**

To achieve cost parity for **400 mile range** & for larger vehicles further reductions are required.

Key Strategies:

- Grow volume, scale & vertical integration
- Commodity Supply Management & Innovation
- **More energy amortized over the same cell & battery hardware.**



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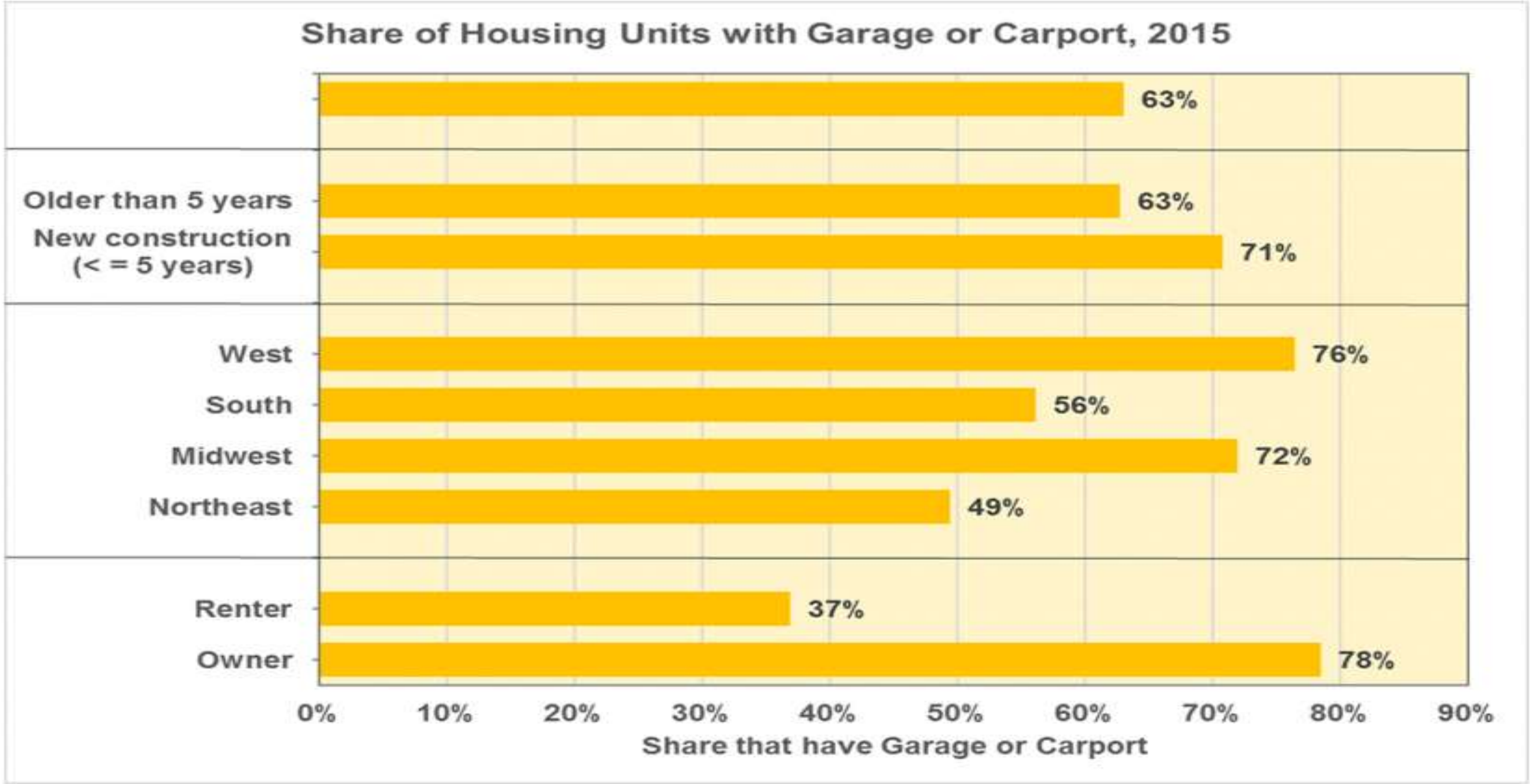
37% of homes in USA will not have easy access to charging

Ref: DOE 2017

SHARE OF HOUSING UNITS WITH A GARAGE OR CARPORT, 2015



Note: A housing unit is a house, apartment, group of rooms, or single room occupied or intended for occupancy as separate living quarters.

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Car Chargers exist that can deliver 200 miles in 10 minutes
- Megawatt scale charging in theory could deliver 200 miles in 5 minutes

Miles available with different charging times & charger Power

Charge Time/mins	Charger Power kW 50	150	350	500	1000
5	15	45	105	150	300
10	30	90	210	300	600
15	45	135	315	450	900
20	60	180	420	600	1200
30	90	270	630	900	1800

Electron Efficient Car (4 miles = 1kWh)

90% Charger Efficiency Assumed

350kW Chargers
- California

…….waiting

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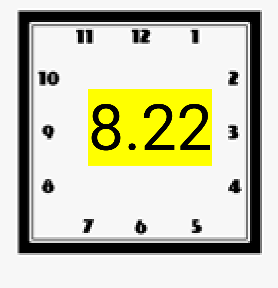
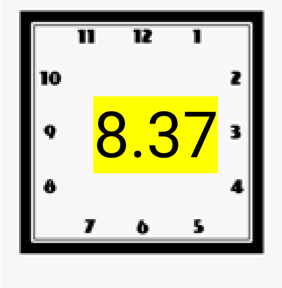
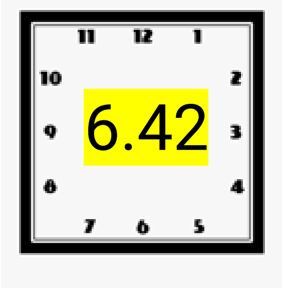
Let’s Play a car game – who gets to DC first

860-mile journey to Washington, DC ?

	A	B	C	D
				
Range	200 miles	400 miles	300 miles	500 miles
Charge Time	15 mins	60 mins	5 mins	15 mins
Battery Energy	67kWh	133kWh	100kWh	167kWh
Vehicle Cost	$30,000	$40,000	$35,000	$45,000
Arrival Times?				

Orlando, FL
Departing @ 6.00am

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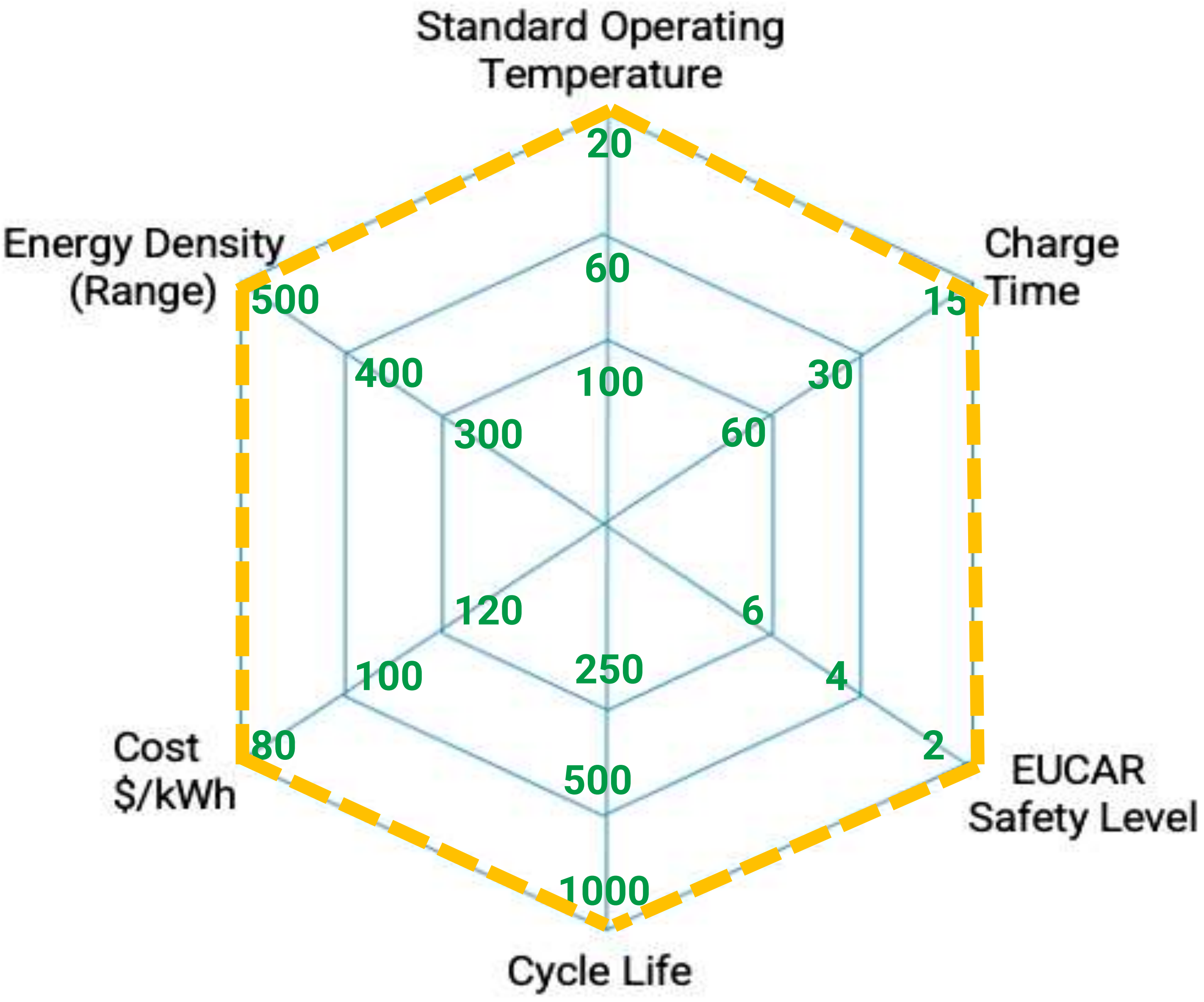
Assumptions: Base car price = $20,000; Battery Price = $150/kWh; 3 miles = 1kWh
5-minute ramp on 5-minute ramp off, 40 miles min “tank”, 80% charge

Eliminating EV Detractors – Still some work to do

Ideal EV Characteristics*

- **500 miles range**
- **1000 cycles Life**
- **No Chance of Fire**
- **Battery heating not req.**
- **Cost =/< ICE**
- **Charging =/< 15 minutes**

* Based on IONICS, VTO and Battery 500 objectives but some may be contrary to business preferences. E.g., 500 miles x 1000 cycles = 500,000-mile vehicle life.



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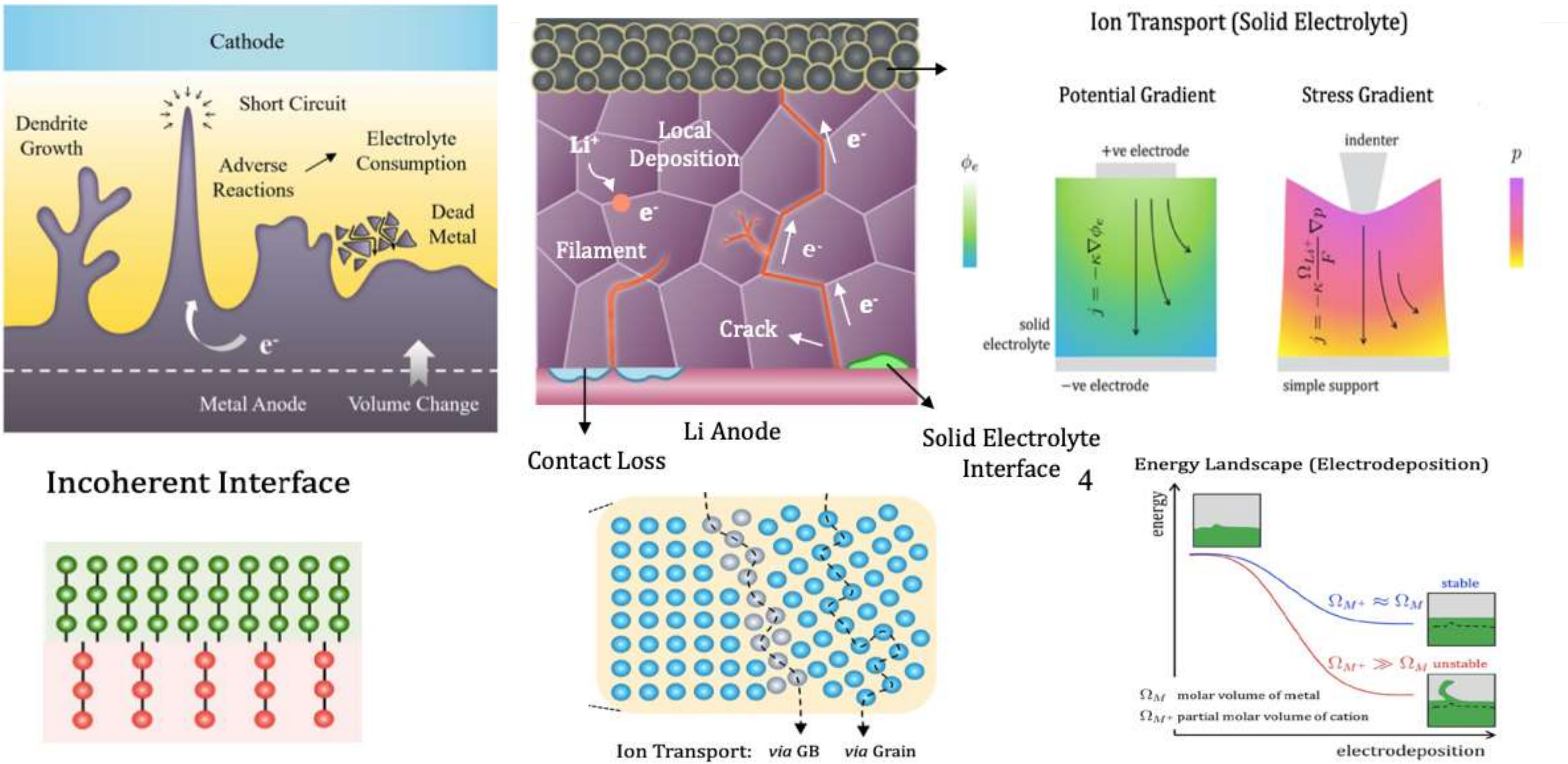
Working towards a Workshop: Understanding the Science



Reference: *Partha Muckherjee, Purdue University, 2020 IONICS Annual Meeting*

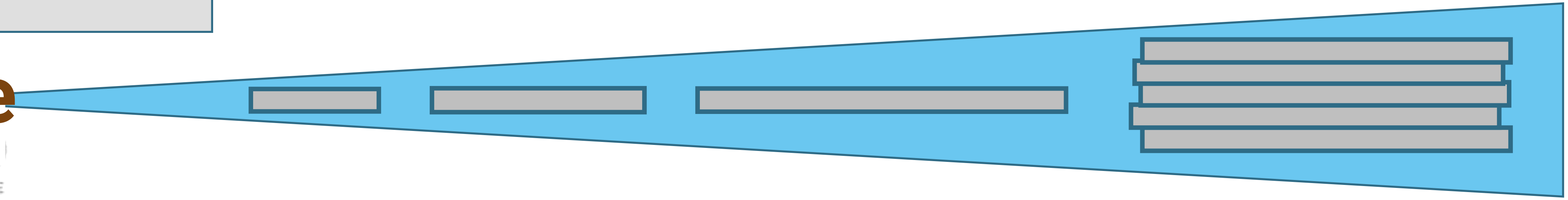
The Purpose of the Workshop is to explore this space

	SOA			
Cell Energy Density – Wh/Kg	250	325	400	500
Charge Time to 80% in mins	120	40	15	5
Miles in 5 minutes	20	50	100	200

Constraints/Opportunities

- Temperature & Pressure
- Capacity Turnover
- Resilience (& Repair)
- Safety & Assurance
- Real $ Advantage
- Manufacturing Segue
- Philosophy
- System Thinking
- Sustainability

Scale



DOE VTO Battery R&D: Near, Next, and Long Term

Focus – this WS

Enhanced Li-ion
Graphite / NMC

Projected Cell Specific Energy, Cost
300Wh/kg, $100/kWh

Current cycle life	> 1000
Calendar life	> 10 years
Mature Manufacturing	Yes
Fast charge	No
Cost positive recycling	No

R&D Needs
- Fast charge
- Low temperature performance
- Low/no cobalt cathodes
- Cost positive recycling

Next Gen Li-ion
Graphite-Silicon Composite / NMC

Projected Cell Specific Energy, Cost
400Wh/kg, ~$75/kWh

Current cycle life	> 1000
Calendar life	~3 years
Mature Manufacturing	No
Fast charge	Yes
Cost positive recycling	No

R&D Needs
- Enhanced calendar life
- Abuse tolerance improvement
- Low/no cobalt cathodes
- Cost effective and scalable pre-lithiation

Lithium Metal
Li metal/NMC, DRX, Sulphur, other

Projected Cell Specific Energy, Cost
500Wh/kg, ~$50/kWh

Current cycle life	> 300
Calendar life	???
Mature Manufacturing	No
Fast charge	???
Cost positive recycling	No

R&D Needs
- Enhanced cycle and calendar life
- Protected lithium
- Dendrite detection and mitigation
- Cost effective manufacturing
- High conductivity solid electrolyte

The things that are IN and the things that are NOT

The Grid

CONVENIENCE IN GENERAL

Whole EVs

Charger Hardware

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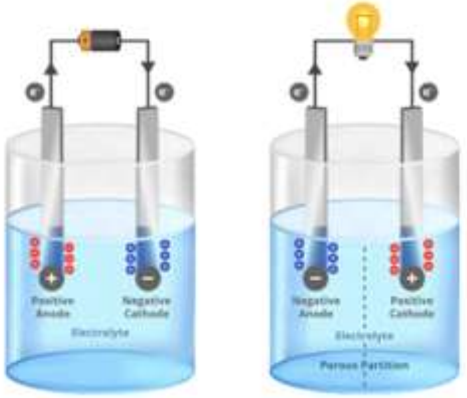
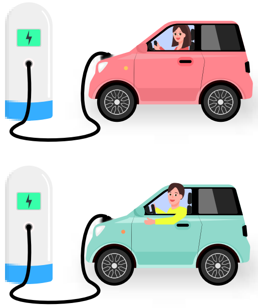
<u>Cell</u> chemistries, Designs, Processes, Treatments, etc > 450Wh/Kg



FAST CHARGING IN PARTICULAR

FULL Batteries

Charging Protocols & Environments



Looking at the Agenda from here….

Professor Paul Albertus – Where have we come from?

Professor Partha Muckherjee – The challenges of Crosstalk!

Three Panels – Batteries, Automotive OE and Charger Hardware

Three Breakout Groups – *Where do we want to go, what will stop us getting there and what will it look like when we do?*

Gatherly Networking – tonight at 4.35pm

Grigorii

Max

Scott

Marina

Dawson

Peter

Phil

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"Great people are forged in Fire.
It is the Privilege of lesser folk
to light the flame." – The War Doctor